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FREE-FLIGHT TESTING OF AERODYNAMIC DECELERATORS IN A SUPERSONIC WIND TUNNEL

L. K. Ward and A. W. Myers
ARO, Inc.

June 1967

VON KÁRMÁN GAS DYNAMICS FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

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Arnold Engineering Development Center
Air Force Systems Command
Arnold Air Force Station, Tennessee

The model erroneously referred to as the supersonic glide surface parachute in the above report should consistently be referred to as the supersonic guide surface parachute.

NOTICES

FREE-FLIGHT TESTING OF AERODYNAMIC DECELERATORS IN A SUPERSONIC WIND TUNNEL

L. K. Ward and A. W. Myers
ARO, Inc.

FOREWORD

The work reported herein was done at the request of the Air Force Flight Dynamics Laboratory (AFFDL), Air Force Systems Command (AFSC), under Program Element 62405364, Project 6065.

The results of the developments presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), AFSC, Arnold Air Force Station, Tennessee, under Contract AF 40(600)-1200. The work was conducted under ARO Project No. VT0626, and the manuscript was submitted for publication on April 17, 1967.

The authors wish to acknowledge their colleague, Mr. C. J. Schueler, who suggested testing the decelerators in the free-flight mode, for his efforts throughout the program and Mr. C. A. Babish of the Air Force Flight Dynamics Laboratory for supplying the parachute models.

This technical report has been reviewed and is approved.

James N. McCready
Major, USAF
AF Representative, VKF
Directorate of Test

Leonard T. Glaser
Colonel, USAF
Director of Test

ABSTRACT

A technique has been developed for use in the continuous flow, supersonic Tunnel A of the von Kármán Gas Dynamics Facility to obtain drag and performance data on flexible decelerators deployed behind models in free flight. The technique is described, and drag data obtained on two parachute configurations are compared with data obtained using a strut-supported model.

CONTENTS

ILLUSTRATIONS

TABLE

NOMENCLATURE

A	Parachute frontal area, in.^{2}
a_X	Acceleration of the model in the X direction with respect to a tunnel fixed axis, ft/sec^2
C_D	Parent model total drag coefficient, drag/q_∞A
C_{D_P}	Parachute drag coefficient
C_{D_T}	System total drag coefficient ($C_D + C_{D_P}$)
d	Model base diameter, in.
M_∞	Free-stream Mach number
m	Model mass, slug
Re_d	Free-stream Reynolds number, based on maximum diameter of parachute
V_{X_F}	Velocity of the model in the X direction with respect to the media fixed axis, ft/sec
x	Distance from the model base to parachute canopy, in.
λ_t	Total parachute porosity, percent
ρ_∞	Free-stream density, slug/ft^3

SECTION I
INTRODUCTION

Aerodynamic decelerators have been of interest for many years as a means of safely descending payloads through the lower atmosphere at very low speeds. With the advent of high-speed flight and later the "space age", deployable decelerators are being used to lessen the speed of re-entry vehicles at supersonic and even hypersonic speeds.

The wind tunnel may be used to advantage in the development of high-speed aerodynamic decelerators. Several tests have been conducted at the von Kármán Gas Dynamics Facility (VKF), AEDC and are summarized in Ref. 1. The most widely used technique for testing decelerators in a wind tunnel is to support the parent body (forebody) model by means of one or more side-mounted struts, leaving the region behind the base of this model unobstructed. The drag on the trailing decelerator is determined using a load cell which may be located in the forebody or outside of the wind tunnel. Because of the high loadings generally encountered in this type of test, the supporting struts are necessarily large and are therefore subject to generate unwanted interference in the forebody wake. Such interference could affect the decelerators' performance and drag characteristics.

A wind tunnel free-flight testing technique (Ref. 2) has been developed at VKF for testing at Mach numbers ranging from 1.5 through 10. This technique was used to obtain data on a parachute trailing behind a cone-cylinder-flare model at Mach 4. The technique is described and results of this test are reported herein for comparison with data obtained using a double strut support cone-cylinder-flare model. The tests were conducted in the 40-in. supersonic tunnel (Gas Dynamic Wind Tunnel, Supersonic (A)).

SECTION II
APPARATUS

2.1 WIND TUNNEL

Tunnel A is a continuous, closed-circuit, variable density wind tunnel with an automatically driven, flexible-plate-type nozzle and a 40- by 40-in. test section. The tunnel operates at Mach numbers from 1.5 to 6 at maximum stagnation pressures from 29 to 200 psia, respectively, and stagnation temperatures up to 300°F ($M_\infty = 6$). Minimum

operating pressures range from about one-tenth to one-twentieth of the maximum pressures.

2.2 MODELS

The parent model used during the tests was a spherical nose, cone-cylinder-flare. Both the free-flight model and the captive model were of the size shown in Fig. 1.

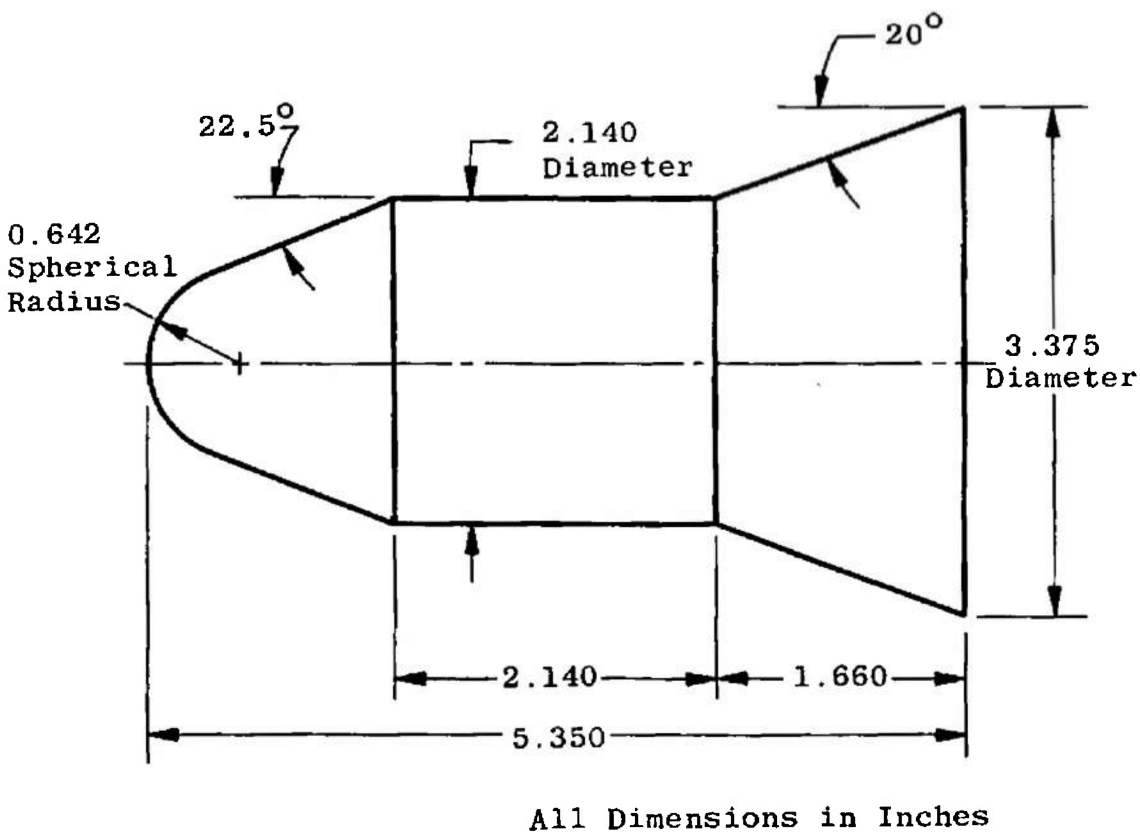
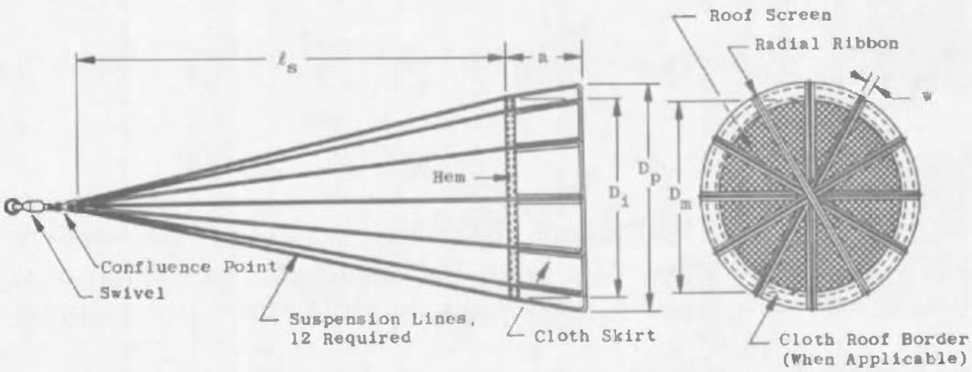


Fig. 1 Sketch of the Parent Model

Two types of parachutes, hyperflo and supersonic glide surface, were utilized during the investigation. The hyperflo parachutes, characterized by a truncated cone design, were constructed with porous roofs and solid-cloth, low porosity skirts. Construction and design details of the hyperflo parachutes are shown in Fig. 2.



a. Typical Hyperflo Construction

Config. Number	λ_t, percent	D_p, in.	D_m, in.	D_i, in.	a, in.	ℓ_s, in.	w, in.	Suspension Line Material	Material	Roof Border and Radial Ribbon Material	Roof Screen Material
1	15	5.00	4.78	4.50	1.44	10.00	0.15	Cord, Nylon 100-lb MIL-C-5040, Type 1	Cloth, Nylon 300-lb/in. MIL-C-8021, Type II	Neoprene-Coated Nylon Dantex® 5678	Perlon Mesh 25/2/280, 64 by 64 Grid (per in.)
3	5	5.00	2.90	4.50	1.44	10.00	0.15				

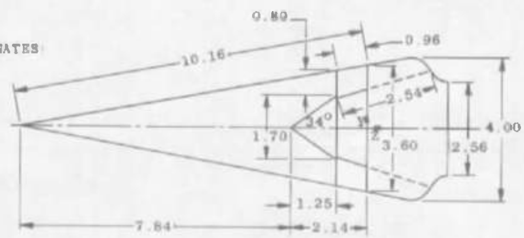
b. Hyperflo Design Specifications

Fig. 2 Hyperflo Porochute Construction and Design Specifications, Configs. 1 and 3

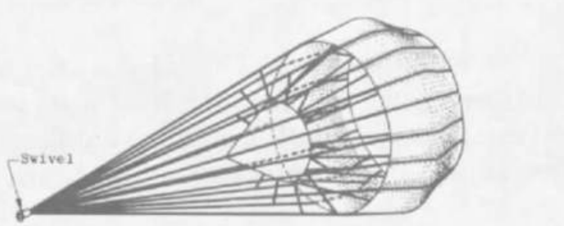
The supersonic glide surface parachutes were designed with a rigid conical centerbody at the inlet and a flexible, low porosity, cloth canopy. Details of the design and construction of the parachutes are shown in Fig. 3 and discussed in detail in Ref. 3.

CANOPY PROFILE COORDINATES

Z, in.	Y, in.
0	1.784
0.50	1.876
1.00	1.976
1.10	1.996
1.20	2.000
1.30	1.996
1.40	1.984
1.50	1.956
1.60	1.904
1.70	1.824
1.80	1.696
1.90	1.552
2.00	1.440
2.10	1.368
2.20	1.316
2.30	1.288
2.35	1.280



Canopy Material	Cone Material	Suspension Lines
300-lb/in. Nylon Cloth MIL-C-802 A, Type II	300-lb/in. Nylon Cloth Filled with Polyurethane Foam	100-lb Nylon Cord, MIL-C-5040, Type I



All Dimensions in Inches

Fig. 3 Supersonic Glide Surface Porochute Construction and Design Specifications, Config. 74

2.3 MODEL SUPPORTS

2.3.1 Free-Flight Tests

During the free-flight phase of the test program, the models were launched from a pneumatically operated launcher. A sketch of the launcher is shown in Fig. 4. The launcher consists of an aluminum piston which is contained in a stainless steel case and guide. The piston stroke is about 6.5 in. and will launch models at velocities up to 100 ft/sec.

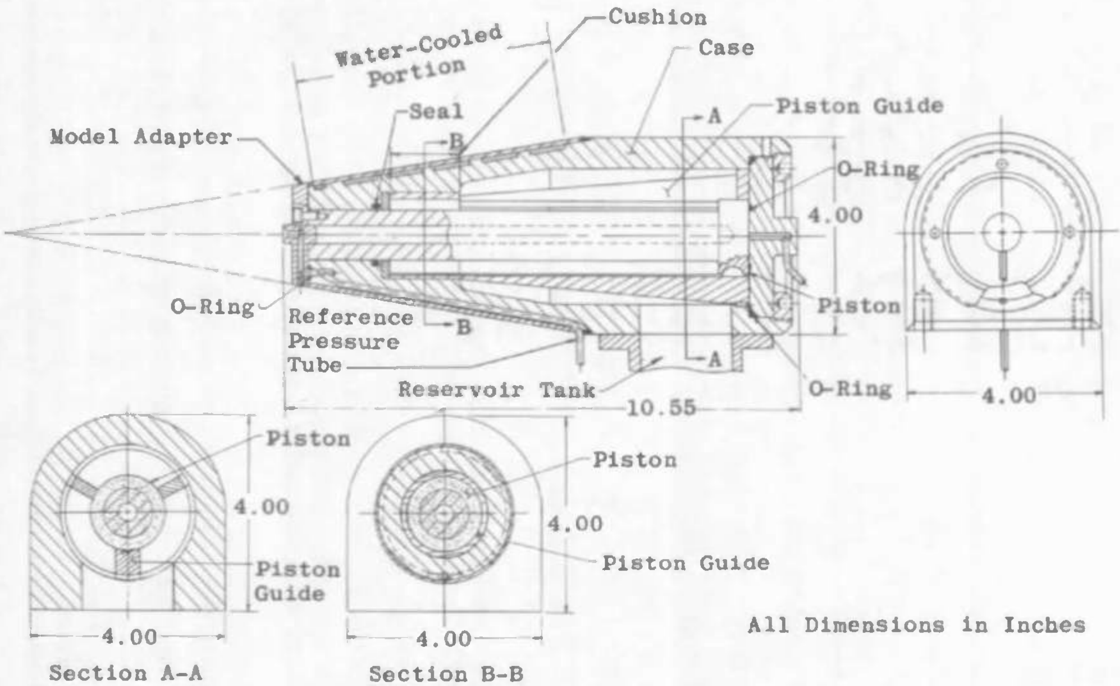
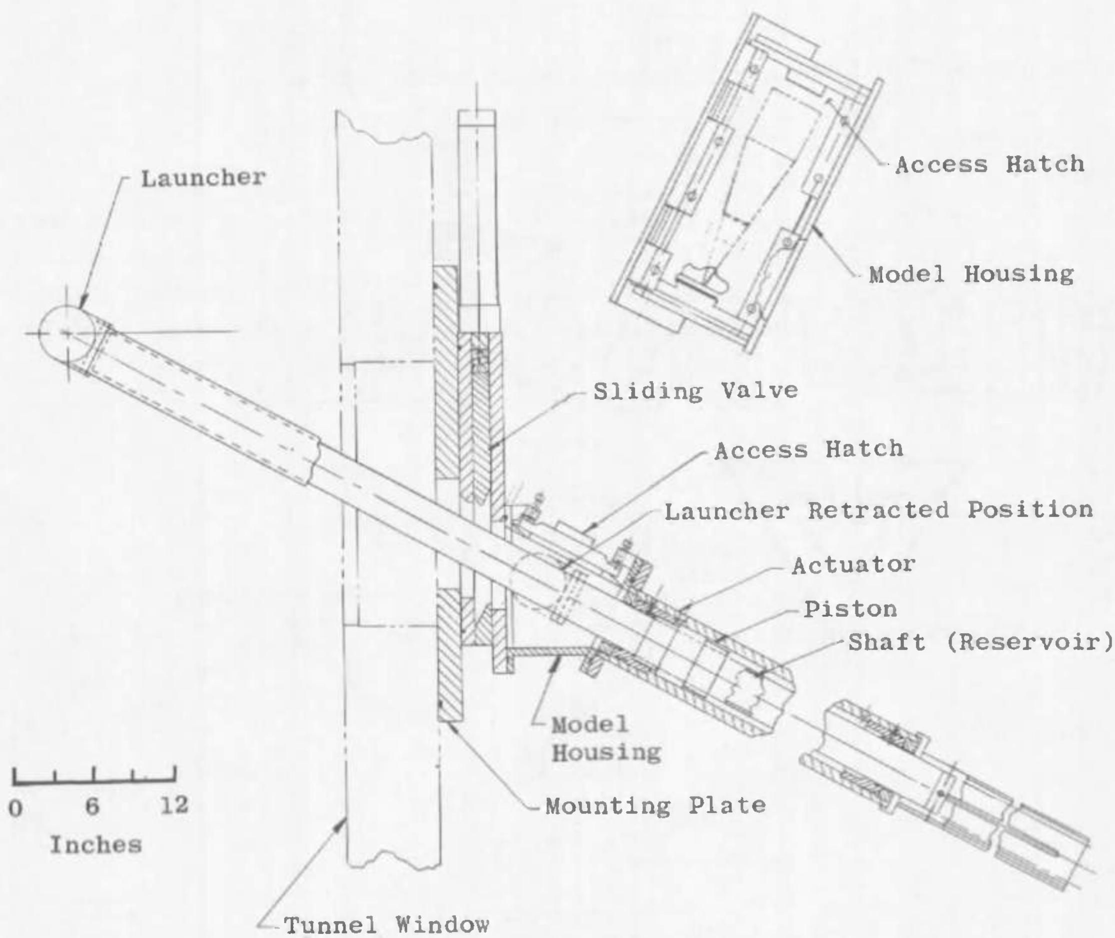


Fig. 4 Model Launcher

The launcher, when used in Tunnel A, is supported on an injection/retraction system (Fig. 5), which is provided to allow the launching of several models without interrupting the operation of the tunnel. A more detailed description of the launcher system may be found in Ref. 2.



Looking Downstream

Fig. 5 Tunnel A Launcher Support System

2.3.2 Captive Tests

The support system for the captive forebody phase of the investigation consisted of a strut spanning the width of the tunnel and mounted to the sidewalls. The tensiometer for measuring parachute drag was housed in a vacuum tank, which was also mounted to the tunnel sidewall. The decelerator support line passed through the model and strut and into the vacuum tank, where it was attached to the tensiometer. Care was taken to duplicate the bridle riser-line attachment used during the free-flight testing. Details of the system are presented in Fig. 6.

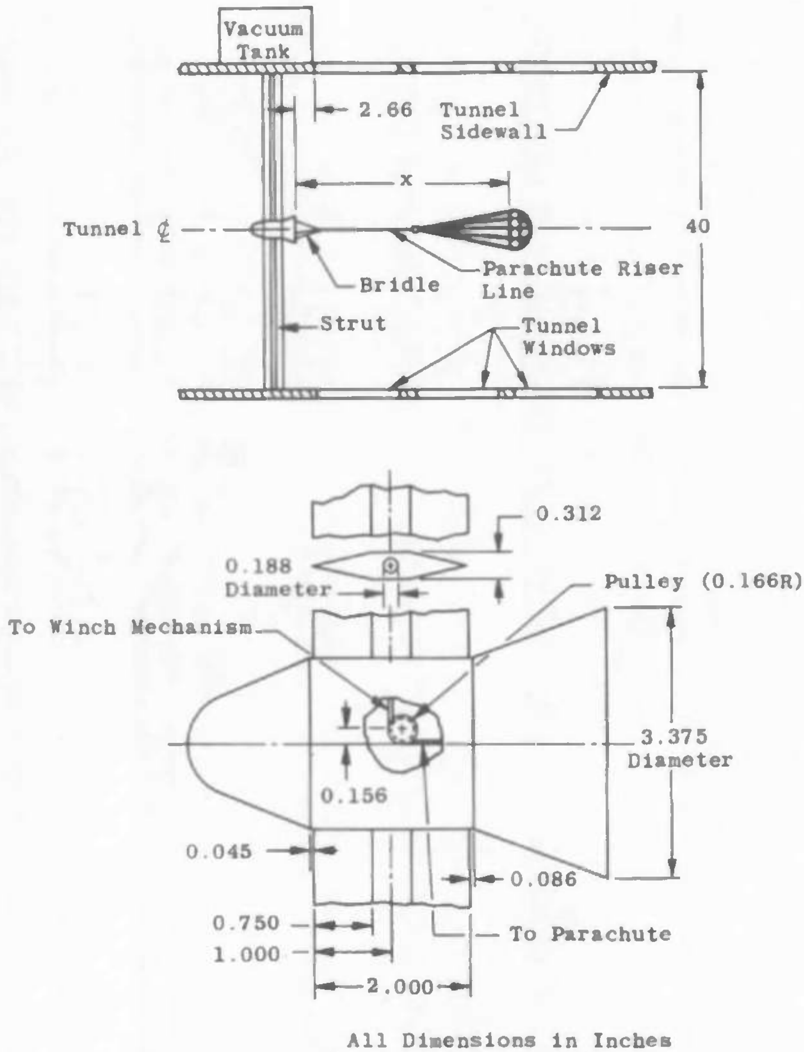


Fig. 6 Forebody and Strut Support for the Captive Tests

SECTION III
PROCEDURE

3.1 FREE-FLIGHT TESTS

The basic objective of the free-flight wind tunnel tests was to package the parachute inside the model and then to deploy it in an orderly fashion while the model was in flight. A model scale was chosen so that existing parachutes could be used. The final model-parachute assembly is shown in Fig. 7, and the sequence of events during chute deployment is shown in Fig. 8.

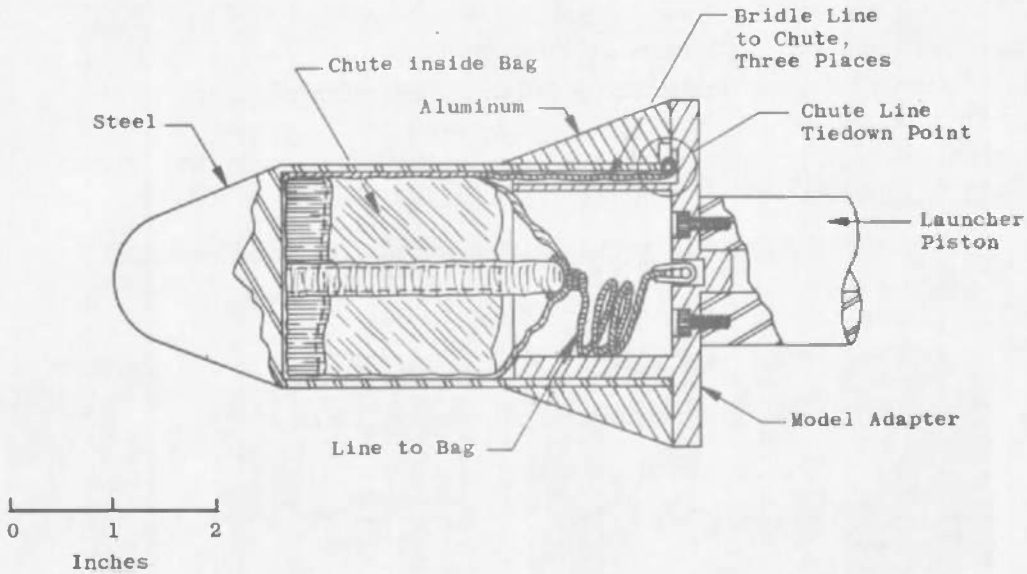
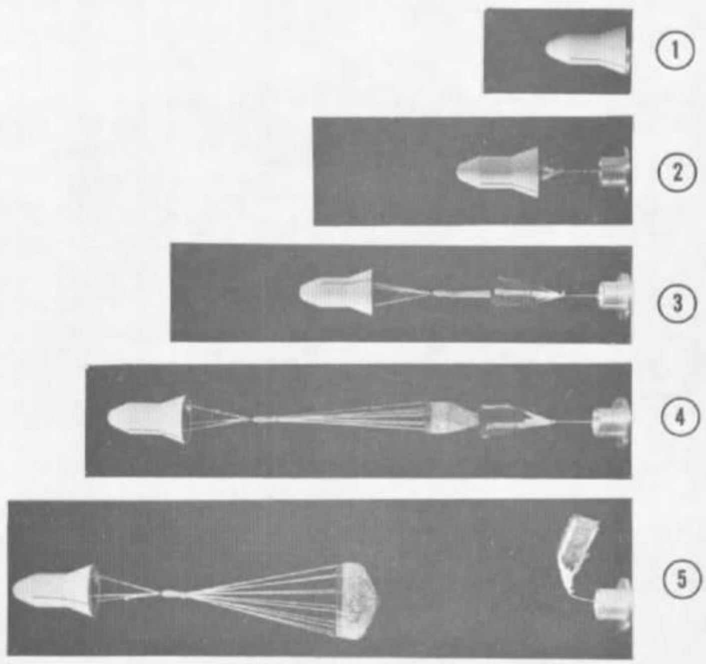


Fig. 7 Free-Flight Model-Parachute Assembly



1. Piston at end of stroke, model still on adapter.
2. Model moving away from adapter.
3. Chute bag out, shroud lines being pulled from bag.
4. All lines extended.
5. Chute deployed.

Fig. 8 Parachute Deployment Sequence

During each run, model motion was recorded by two high-speed (4000-frames/sec), 16-mm motion-picture cameras. One camera was used to film the total viewing area, and selected frames taken by this camera are shown in Fig. 9. The second camera was used in conjunction with the tunnel schlieren system and viewed only the tunnel upstream window.

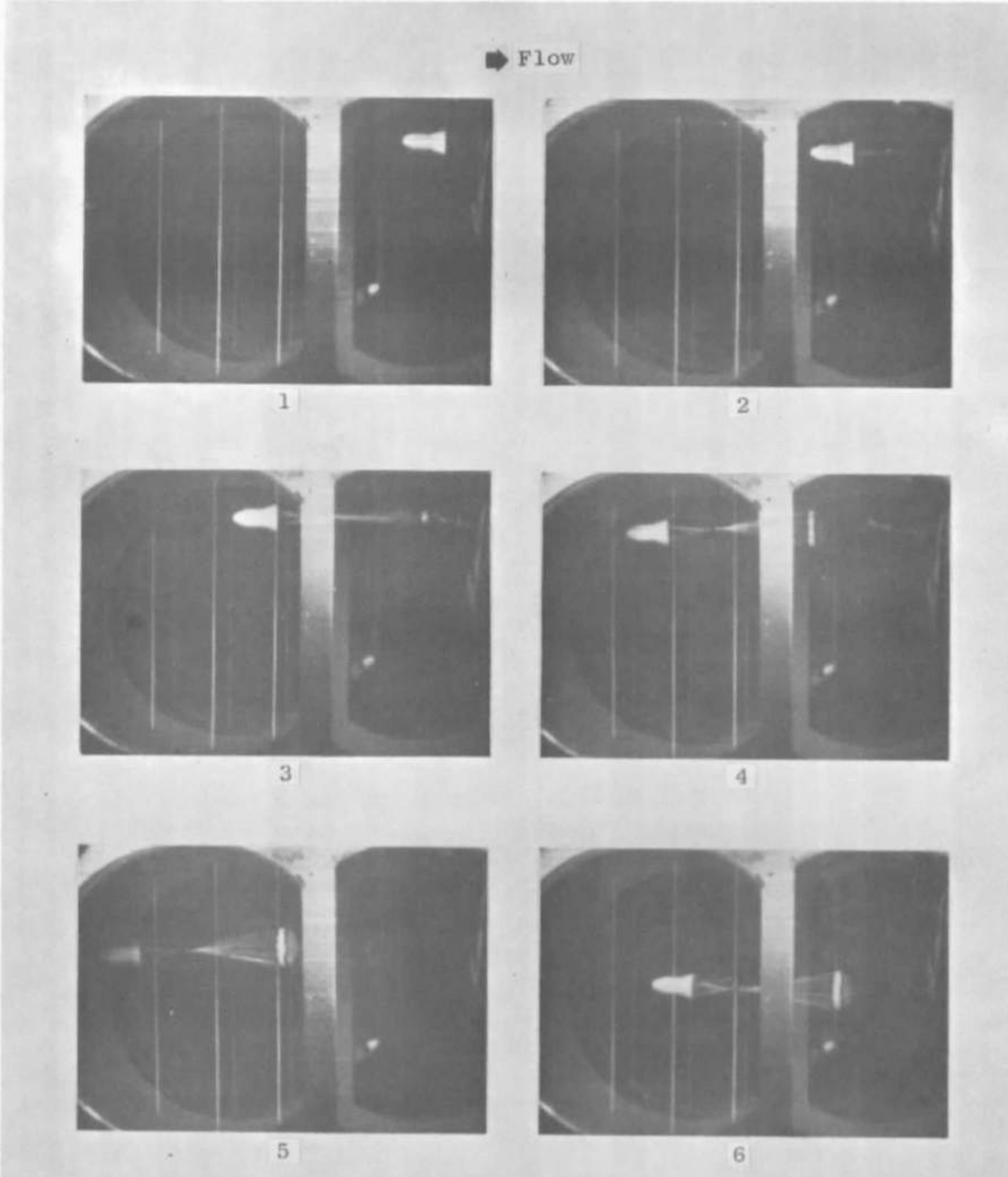


Fig. 9 Free-Flight Deployment at Mach 4, Config. 1, x/d = 4.9

All drag data were obtained using motion data recorded with the second camera. With the aid of a film reader, the models' motion time history was obtained, and the model and parachute drag coefficient was determined as

$$C_{D_T} = \left(2m/\rho_\infty A V^2_{X_F}\right) a_X$$

The above equation simply comes from Newton's Second Law, and a more detailed treatment of the development of the equations of motion may be found in Ref. 2.

Two models of the parent body were launched without the parachute to determine the total drag coefficient (C_D) of the parent model alone. The parachute drag coefficient may then be found as

$$C_{D_P} = C_{D_T} - C_D$$

where C_D is also based on the frontal area of the parachute.

3.2 CAPTIVE TESTS

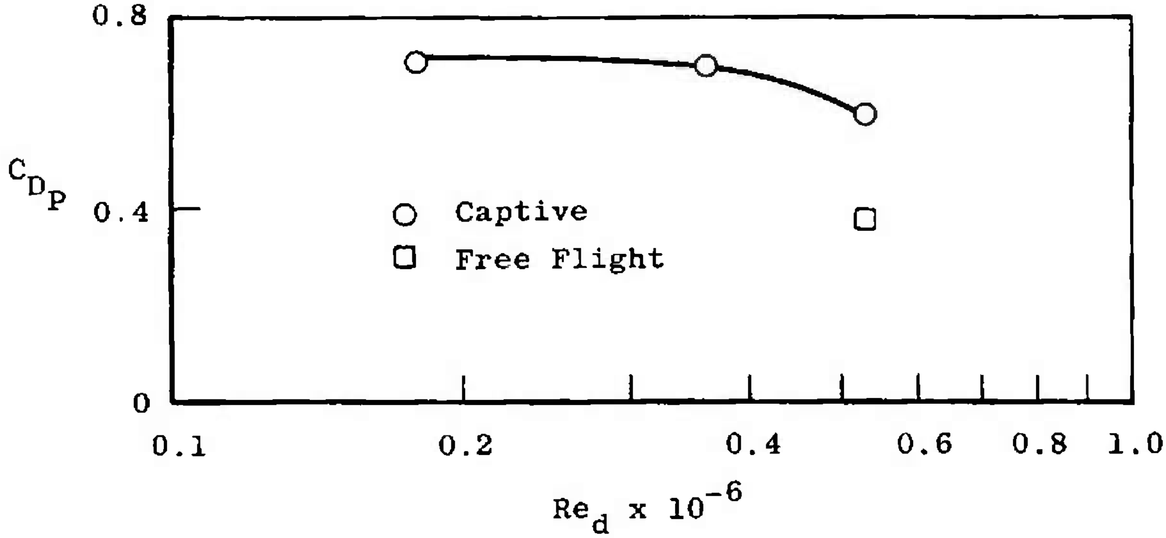
Before each test run, the parachute canopy and suspension lines were packed in a deployment bag, which was then suspended near the base of the parent model by a pull cord routed from the rear of the bag through the tunnel sector. The pull cord was held taut manually during tunnel start, and when the desired test condition was established, a sharp pull on the cord removed the bag. The normal procedure for remotely varying x/d during tunnel operation was not used since all data were obtained with the parachute riser line attached to a bridle (Fig. 6) to duplicate the free-flight test configuration.

SECTION IV
RESULTS AND DISCUSSION

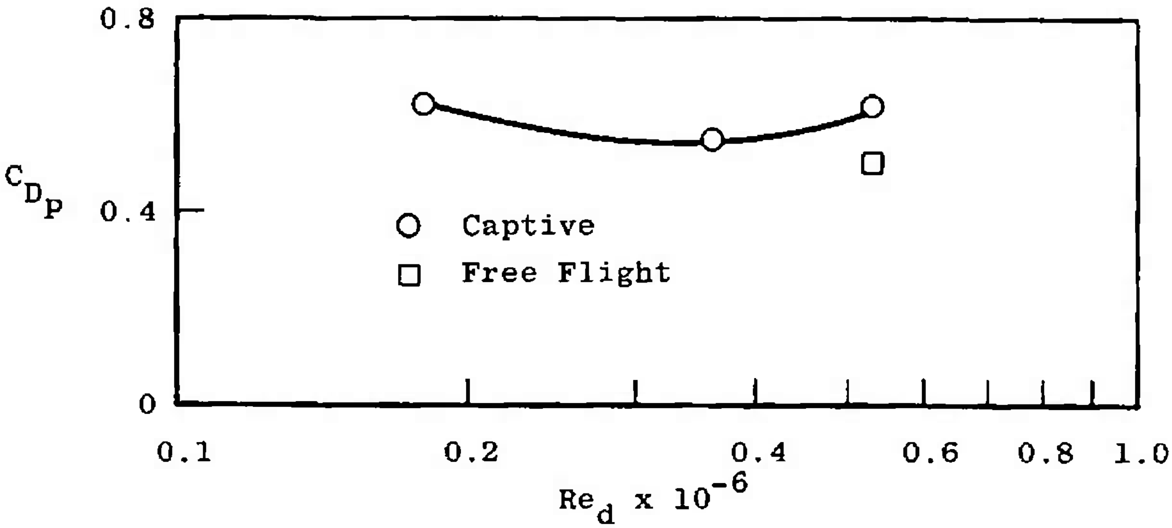
Two basic parachute configurations, a hyperflo parachute model and a supersonic glide surface parachute model (Config. 74), were tested using the two techniques. Two total canopy porosities, $\lambda_t = 5$ (Config. 1) and $\lambda_t = 15$ (Config. 3), were tested for the hyperflo parachute.

Parachute drag data obtained on the hyperflo parachutes are shown in Figs. 10 and 11. The comparison of the data obtained during the

captive tests and the free-flight tests for x/d = 4.9 (Fig. 10) shows the captive model drag to be higher for both values of λ_t. Figure 11 shows that increasing the parachute trailing distance to about 4.5 base diameters did not affect the difference in drag obtained by the two testing techniques.



a. λ_t = 5 (Config. 3)



b. λ_t = 15 (Config. 1)

Fig. 10 Parachute Drag Coefficient versus Reynolds Number, (Hyperflo) x/d = 4.9

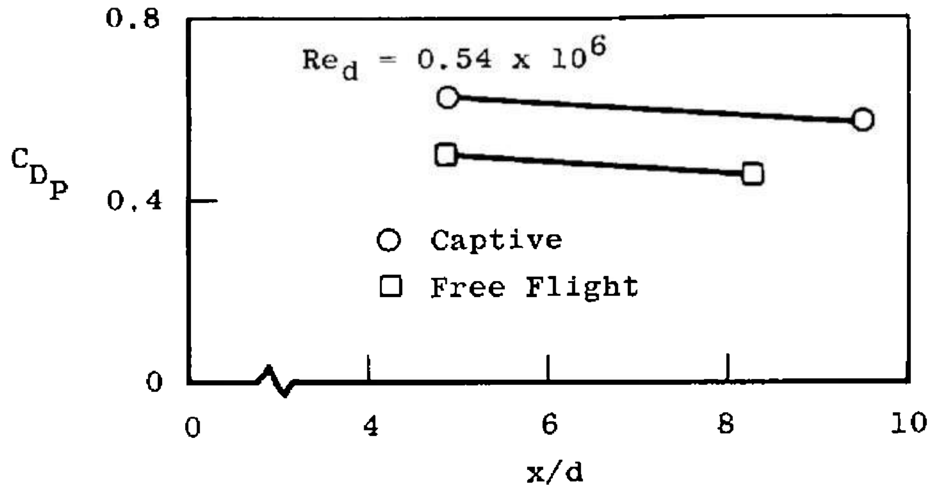


Fig. 11 Parachute Drag Coefficient versus Trailing Distance in Base Diameters, Config. 1 (λ_t = 15)

Data obtained on the supersonic glide surface parachute model (Config. 74) are given in Fig. 12 and again show the captive model data to be high with respect to the free-flight results.

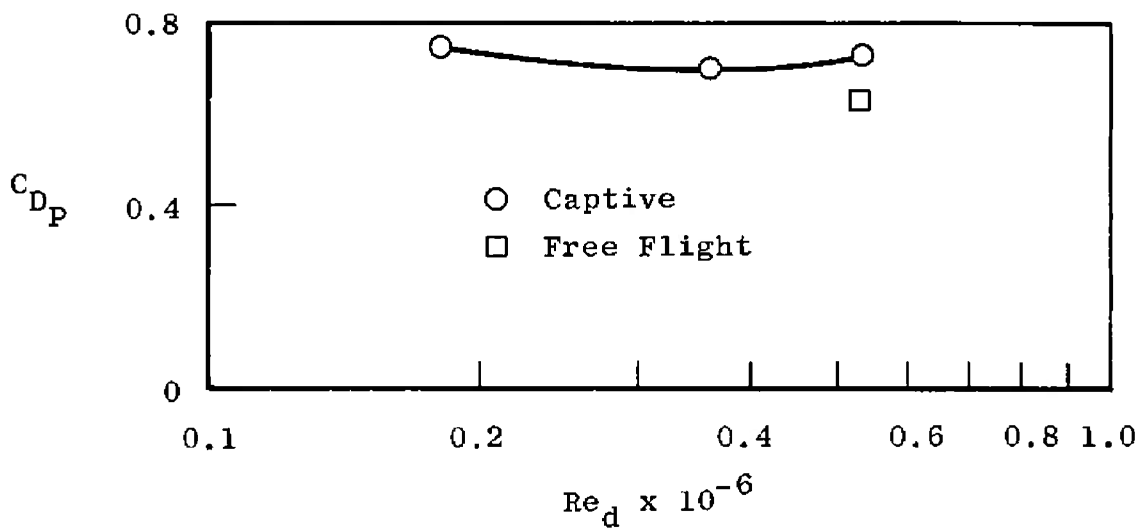


Fig. 12 Parachute Drag Coefficient versus Reynolds Number, Supersonic Guide Surface, Config. 74, x/d = 9.1

A summary of the parachute's performance is given in Table I.

TABLE I
PARACHUTE PERFORMANCE

Configuration	λ_t, percent	M_∞	$Re_d \times 10^{-6}$	x/d	Remarks
1 (Hyperflo)	15	4.0	0.54	4.9	Free flight - Good canopy inflation with little or no oscillation. Shroud lines flexing lightly and canopy slowly spinning on most runs.
					Captive - Oscillations of 0.5 deg with very light canopy pumping. Shroud lines flexing lightly but not spinning.
				8.3	Free flight - Bad canopy opening. Model pitching and canopy pumping throughout run.
				9.5	Captive - Oscillations of 2 to 7 deg. Heavy pumping of canopy with shroud lines flexing moderately.
3 (Hyperflo)	5	4.0	0.54	4.9	Free flight - Canopy steady after initial opening.
					Captive - Oscillations from 2 to 8 deg accompanied by light to moderate canopy pumping. Shroud lines flexing lightly.
74 (Supersonic Glide Surface)	---	4.0	0.54	9.1	Free flight - Canopy steady after initial opening.
					Captive - Intermittent 5-deg oscillations. Canopy steady otherwise.

SECTION V
CONCLUDING REMARKS

A technique has been developed at VKF to deploy flexible decelerators from free-flight wind tunnel models at supersonic speeds. The free-flight data, when compared with data obtained using a strut-supported model, show that support interference effects possibly exist. The procedures reported for testing up to $M_\infty = 6$ may also be easily used to provide a capability for testing up to $M_\infty = 10$.

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3. Heinrich, H. G. "Aerodynamic Characteristics of the Supersonic Guide Surface and the Spiked Ribbon Parachutes." AFFDL-TR-65-104, December 1965.

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